Haptic Feedback in Automotive and Commercial Vehicle Applications

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ABSTRACT

In times of digitalization as a megatrend, haptic feedback by touch or contact interfaces can be a means to relieve the driver/passenger on other channels of perception while communicating relevant information. In this context, the perceived comfort of haptic systems is particularly important to ensure the best possible user product interaction. Two ergonomic cross-sectional studies from the automotive and forklift sectors are presented in this contribution. The first study involved the randomized assessment of three different haptic center console devices for automotive applications in a laboratory environment. 21 subjects tested the different devices, which had three activation thresholds of 0.3N/1.0N/2.0N. The second study analyzed haptic feedback in terms of an indication and attention signal in different seats for forklifts. The tested expert group encompassed 8 subjects in the static laboratory study and 4 subjects in the field tests. The results of the first study showed for all three devices that female subjects perceived the defined activation thresholds as higher than the males did. Overall, activation thresholds no higher than 1N were preferred by the sample group. The results of the second study showed ratings for the distinctiveness of the two tested signals ranging from 6 – Sufficient to 10 – Perfect by the tested forklift truck drivers. The results of the first study suggest gender as an influencing factor on the perception of a haptic feedback at the fingertip, which is relevant for the compilation of sample groups in the product validation process. The second study verified the acceptance of a newly implemented haptic technology with an expert sample group.

KEYWORDS

Haptic feedback, perceived quality, automobile, forklift, interfaces

Introduction

In times of digitalization as a megatrend, there appear to be no limits to the visualization of data. Head Up displays in automobiles and displays attached to the cabin and / or multifunctional armrest of commercial vehicles are just a few examples for the increasing availability of information in the operator environment. It is often stated that people take in 80% of the information to be processed via the visual channel. Taking into account the new digital possibilities, it is more important than ever not to overload the operator. The development of smart GUIs, filtering and selecting identified information, enhances the ability to process visual data. Still, in cases where visual control is needed, there is a risk of missing important safety relevant input in driving situations, so this time should be minimized (Burnett & Porter, 2001). The change of sensory channel for communication can be a means to relieve the operator and increase the perceived comfort and safety.

Besides the visual sense, humans have four other senses which provide the brain with information: Hearing, Touch, Taste, and Smell. While the highest priority in the sense ranking, regardless of culture, is sight, the importance of the other four senses seems to vary (San Roque et al., 2015).

Different approaches to address one sense or more of them simultaneously (synesthesia) are being researched. In the context of a hand operated device in an automobile environment, haptics seem to be a promising option (Pitts et al., 2012). In order to help drivers to focus their visual attention on the driving situation instead of other areas like the center console, multifunctional prototype devices with haptic feedback were developed. The scope of the first study was to assess system characteristics of three different center console devices for automotive applications regarding their influence on perceived comfort. In addition to the application for automobiles, the commercial vehicles sector in particular offers enormous potential for this technology, since areas of operation often exhibit high noise levels such as in the material handling sector (Dass, Uyttendaele & Terken, 2013). Highly demanding environments like warehouses or factories are common areas of application for forklift trucks. Here, the operator has to focus on the tasks at hand like the transport or stacking of goods while at the same time continuously monitoring his/her environment for safety reasons (e.g. pedestrians). The purpose of the second study was to rate the implementation of haptic feedback in an operator seat as also the signal specifications for two different signals.

Methods

Automotive Study

This cross-sectional study was conducted in a controlled laboratory environment. Three different console devices, in which haptic feedback was implemented in individual technical solutions, were tested in randomized order by a sample group consisting of 21 adult subjects (age: MW = 40, range: 25-62), 6 female and 15 male. Each of the devices had three different activation thresholds. To activate the device, the test subjects had to apply a force with their fingertips higher than the activation thresholds of ≈0.3N / ≈1.0N / ≈2.0N. For device 3, there were two variants 3a/b, which differed from each other regarding the direction of motor rotation. Additionally, device 3a/b had three motor speed settings of 6960rpm / 7830rpm / 8700rpm. For the test set-up, the device´s absolute position was defined while the relative position of the armrest in X-direction towards the device was freely selectable by the test subject. A partly standardized interview was conducted capturing subjective ratings regarding various aspects of the haptic devices. Using a seven-point Likert-type scale, the activation threshold level, signal volume, signal quality and perceived signal intensity were assessed. In addition, a ten-point ordinal scale was used to assess the overall system perception. To exclude a possible influence of system acoustics on haptic perception for reasons of variable reduction, defined sections of the test were performed with earplugs and earmuffs.

Commercial Vehicle Study

The second cross-sectional study was divided into two parts. The first was carried out under controlled laboratory conditions. Three different GRAMMER seats for forklifts with implemented haptic systems were tested in a randomized order by a sample group of 8 subjects, 1 female and 7 male. Prerequisite for study participation was a forklift license and daily use of the vehicle at the working site. The position of the haptic device was configured to the different seat cushions addressing their varying contours and foam thicknesses. Two different signals had been established, an indication signal and an attention signal. The system was implemented in the three different seats for rating perception comparability and effectiveness for different seat sizes and versions. Partly standardized interviews were conducted capturing subjective ratings regarding various aspects of the two haptic signals. Using a seven-point Likert-type scale, the position of the two actuators, signal intensity perception, distinctiveness of the two offered signals and the duration of the signals were assessed. Additionally, a ten-point ordinal scale was used for rating the overall perception of the signals. A six-point ordinal scale was employed to evaluate the potential discomfort perception (showroom t = 0min./short-term t = 20min.) caused by the actuators themselves in combination with pressure distribution measurements. The pressure distribution measurements were conducted for each seat and for 4 subjects. The used hardware was an XSENSOR LX100:48.48.02 system (XSENSOR Technology Corporation, Calgary, Canada) with an X3PRO_V7 software (XSENSOR Technology Corporation, Calgary, Canada) for data post processing. To exclude a potential influence of system acoustics on the haptic perception, defined sections of the testing were carried out with ear plugs and earmuffs.

For the second part of the study, one seat of the above-mentioned (MSG65/521) was installed in an industrial counterbalance forklift for testing in a steel processing factory (Figure 1). 4 subjects, 1 female and 3 male, tested the indication signal of the system for at least 30 min. during a regular dayshift. To capture the subjective perceptions for the occurring use cases, forward/rearward driving and pallet stacking (pick-up/drop-off), a partly standardized interview was conducted afterwards. The actuator position, signal intensity and duration were rated using a seven-point Likert-type scale.

Figure 1: Industrial counterbalance forklift and exemplary seating system

Selected Results and Work in Context

Automotive Study

The results of the first study showed a high spread in the perception of the activation thresholds, ranging partially from 1 – Much too low to 7 – Much too high for system 1. The medians of the male subjects were 3 – Slightly too low (0.3N) / 4 – Exactly right (1.0N) / 7 – Much too high (2.0N) for the three activation thresholds and thereby lower in comparison to the female medians of 4 – Exactly right (0.3N) / 6 – Too high (1.0N) / 7 – Much too high (2.0N). In general, female subjects perceived the activation thresholds for all three tested devices as higher than the males did. Independent of the device´s feedback and geometry the male´s preferred threshold was 1.0 N in comparison to the females of 0.3N. Overall, activation thresholds no higher than 1.0N were favored by the sample group.
All ratings in the form of a box-/scatterplot divided according to the system and the gender on a seven-point Likert-type scale is displayed in figure 2. Here, the acceptance range of the sample group is illustrated by the dashed blue lines.

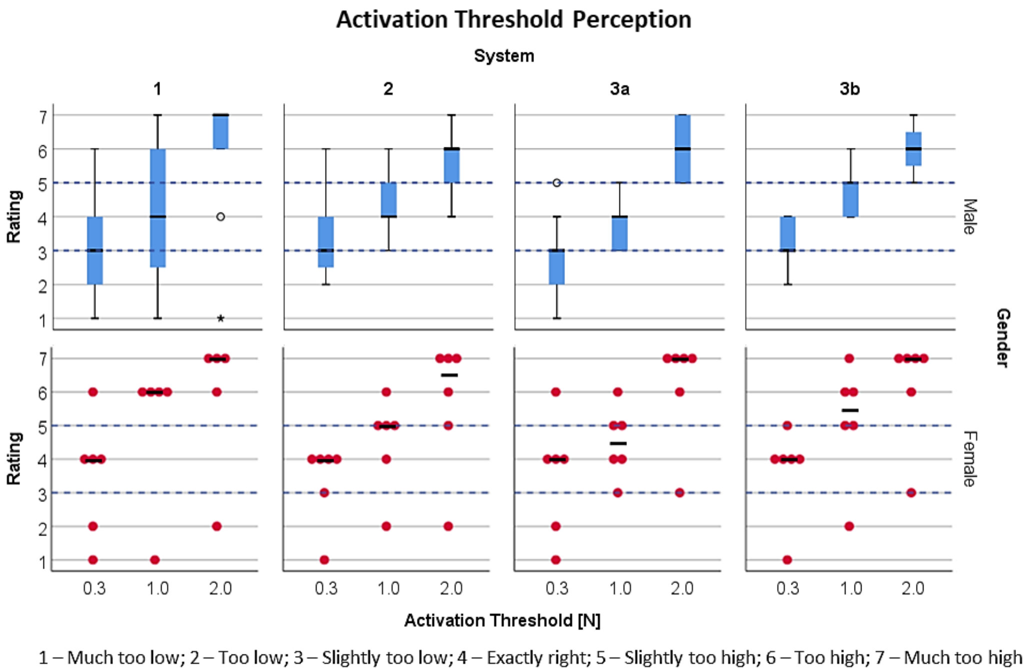

Figure 2: Box-/scatterplot of the activation threshold perception divided by gender

The results of the feedback strength as one factor of the perceived signal comfort showed similar results for both systems 3a / 3b. The offered intensity “low” with 6960rpm was rated by the sample group with medians of 3 – Slightly too weak (3a) and 2 – Too weak (3b). The medians of the “medium” intensity representing 7830rpm were identical, 3 – Slightly too weak and were thus within the acceptance range of the user group. The ratings of the “high” intensity with 8700rpm were partly outside of this range with 5 – Slightly too high (3a) and 6 – Too high (3b). Overall, the preferred intensity of the user group was “medium” (7830rpm). The ratings in form of a box-/scatterplot divided according to system and signal intensity with the associated acceptance range (dashed blue lines) on a seven-point Likert-type scale is displayed in figure 3.

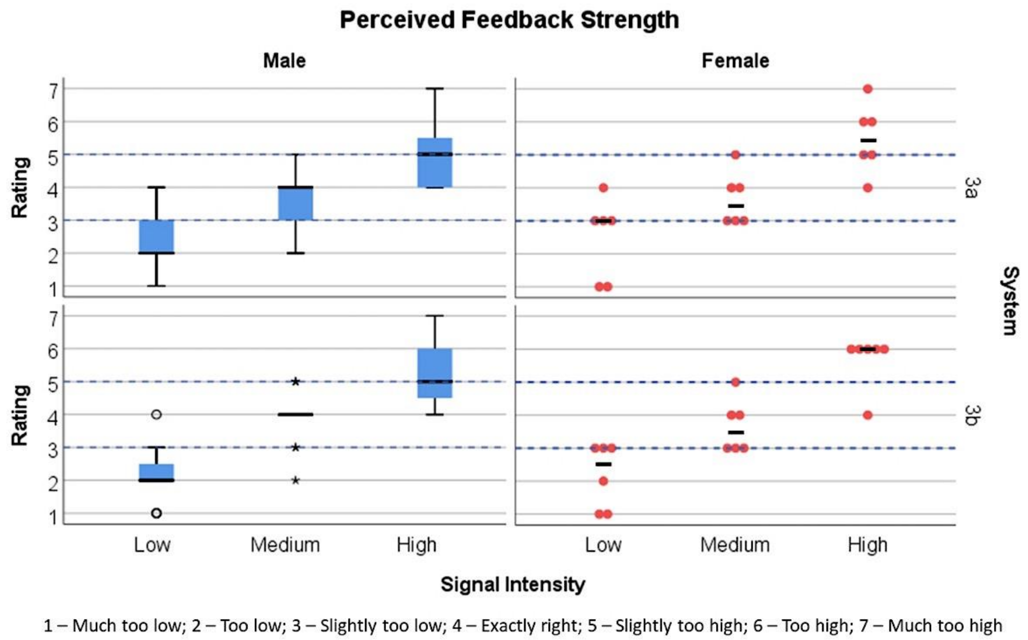

Figure 3: Box/scatterplot of the perceived feedback strength for the three tested signal intensities divided by gender

When the user group is divided by gender, the preferred intensity for both systems 3a / 3b is still “medium”. A slight trend could be observed for the intensities "low" and "high", such as female subjects perceived them as higher compared to male subjects. Confoundingly, this was reversed for the “medium” intensity, however, the difference was very small. Still, the data did not show a conclusive tendency for one gender being more or less sensitive to haptic signals at the fingertip. One possible reason is the small quantity of female participants in this study. In total, signal intensities around 7830rpm (“medium”) for the rated systems 3a / 3b were preferred by the sample group. The direction of motor rotation did not significantly influence the results within the users´ acceptance range. In this study, vibration as a haptic signal as implemented in System 3a / 3b was preferred by both genders over other types of signals (e.g., clicking).
Overall, the tested sample group showed an activation threshold of ≤1.0N for fingertip touch haptic devices in vehicle contexts. The “medium” intensity representing 7830rpm had highest acceptance among the user group with no influence of direction of motor rotation having been apparent. Even though the sample size was a limiting factor for statistical analysis of gender differences, the results strongly suggest taking gender into account when evaluating haptic devices to ensure an optimized comfort during use for the targeted user population.

Commercial Vehicle Study

In the first part of the forklift-truck user study, the pressure distribution and associated comfort and discomfort on three seats was assessed. An important finding was that the implementation of the actuators in the seat cushion did not result in any increase in discomfort or change in local peak pressures / pressure distributions on the cushion (Figure 4). Two positions that are typical for daily work were assumed by the forklift drivers. It was found that the established position of the actuators in X and Y axes as vibration origin were appropriate for both working postures.

Results of the subjective ratings on signal parameters showed that the two signal types (indication / attention) could be well differentiated in the three different seats in realistic sitting positions. The distinctiveness of the two tested signals was given ratings ranging from 6 – Sufficient to 10 – Perfect with one outlier at 5 – Marginal. The attention signal was classified as just right, and as a good alternative to an audio signal which might be overheard. Overall, the configured signals were found to be appropriate for the respective purpose, however, user feedback pointed to improvement potential: In the given configuration, the intensity of the indication signal was rated as slightly too strong. Based on their feedback, signal configuration changes were recommended to product engineering.

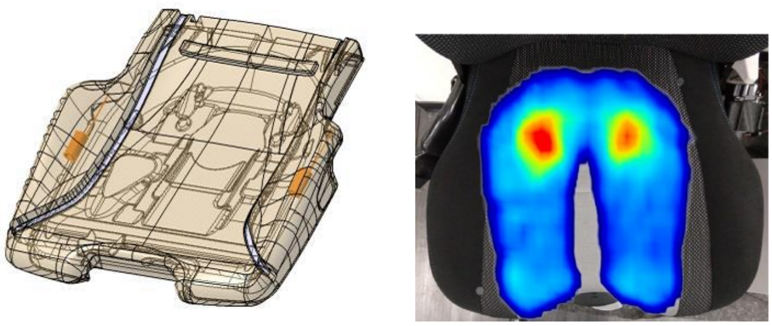

Figure 4: Schematic actuator position in seat cushion (left) and unaffected pressure distribution (right)

In the second part of the study, one of the seats had been installed on a counterbalance truck and was tested under appropriate factory working conditions. Actuator position, signal duration and intensity were observed by the users while operating the forklift and rated positively also under dynamic conditions. Signal distinctiveness and effectiveness was thus confirmed by active forklift users in the prototype seat evaluations. The established configurations were considered as valuable by the expert group and ensure that the haptic signal is perceived by drivers when the vehicle is in operation and operators are in positions activating the operator presence switch.

Conclusions

The user input gained in these comfort projects serve as a basis for defining future products and equipment options, with the aim of optimizing user wellbeing and man-machine performance. Concerning haptic feedback in vehicle contexts, different applications were tested in this research for fingertip and whole-body feedback, and their perception and rating by users was analyzed for verification or further product improvements. It is foreseen that reliably perceived haptic feedback in automotive interior components can support drivers by passing on information in other than the visual channel and thus help keeping eyes on the road (Kuehner, 2014). For fingertip actuation, the activation force between 0.3N and 1N was confirmed as the top comfort threshold for a mixed-gender group. For whole-body feedback by haptic signals in the seat, the configured signal characteristics and actuator positions were verified for the application in counterbalance forklift trucks. Two major advantages that were stated by the professional user group were (1) Haptic channel information does not require directed attention from the drivers, only physical contact, so drivers do not have to be concerned about missing a signal, and (2) the information is "private", i.e. it can only be perceived by the driver and does not additionally pollute the environment. These statements fit with data from earlier studies, such as those by Chang and colleagues (Chang, Hwang & Ji, 2011). In this way, concepts become future-proof by incorporating users, understanding usage, detailing use-cases and forecasting future purposes of interior components and systems. Megatrends and environmental factors are taken into account, such as the continuous increase in signals and need for information processing. Information densities in modern automobiles and material handling vehicles require leveraging all possible sensory channels for information processing.

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